# OBSERVATION OF THE NEARSHORE WATER CIRCULATION OFF A SAND BEACH

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Submitted in partial fulfillment of the
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ABSTRACT

The nearshore circulation off a long sand beach at the southern end of Monterey Bay, California, was studied during February and March 1964. In preparation for the study, various types of floats were tested, and a resumé of the advantages and disadvantages of each type is included as an appendix. Gathering the field data entailed the use of aircraft for aerial photography and an amphibious vehicle for launching and recovering the floats. The wind, wave, and tide conditions prevailing during all of the surveys were nearly the same. The circulation patterns found are presented in the form of schematic charts for each of the five surveys made. The dominant drift was observed to be directly onshore in the area seaward of the surf zone, but inside the surf zone the flow was to the north. Weak circulation cells were found to exist in the surf zone at varying locations along the beach. Current speeds are presented for the onshore drift, the dominant longshore current, the opposing feeder currents to rips, and the rip currents. The speed of the onshore drift was found to be greater than that of the opposing rip currents.

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## 1. Introduction and Acknowledgements.

The research described herein was undertaken to determine the nature of the nearshore circulation patterns off the long crescent-shaped sand beach that marks the inner shoreline of Monterey Bay, California (Fig. 1). The beach area studied is located in the extreme southern end of the bay and includes the beach property owned by the United States Naval Postgraduate School (USNPGS), which was previously known as Del Monte Beach. Five field surveys were made to observe the wind, wave, and tide conditions prevailing during each survey period.

The observational procedure followed in each survey was to place from 14 to 30 free-drifting floats in the water a short distance seaward of the surf zone and to take successive aerial photographs of the floats at known time intervals as they moved in and through the surf zone. The float positions were then plotted and their trajectories thus obtained. From these plots and from visual examination of the photographs, the general circulation patterns and the speeds of the currents near and in the surf zone were established. The causes of the circulation patterns were then examined with respect to the wind, wave, and tide conditions prevailing. Because floats were used in measuring currents, only the surface circulation was examined in this study.

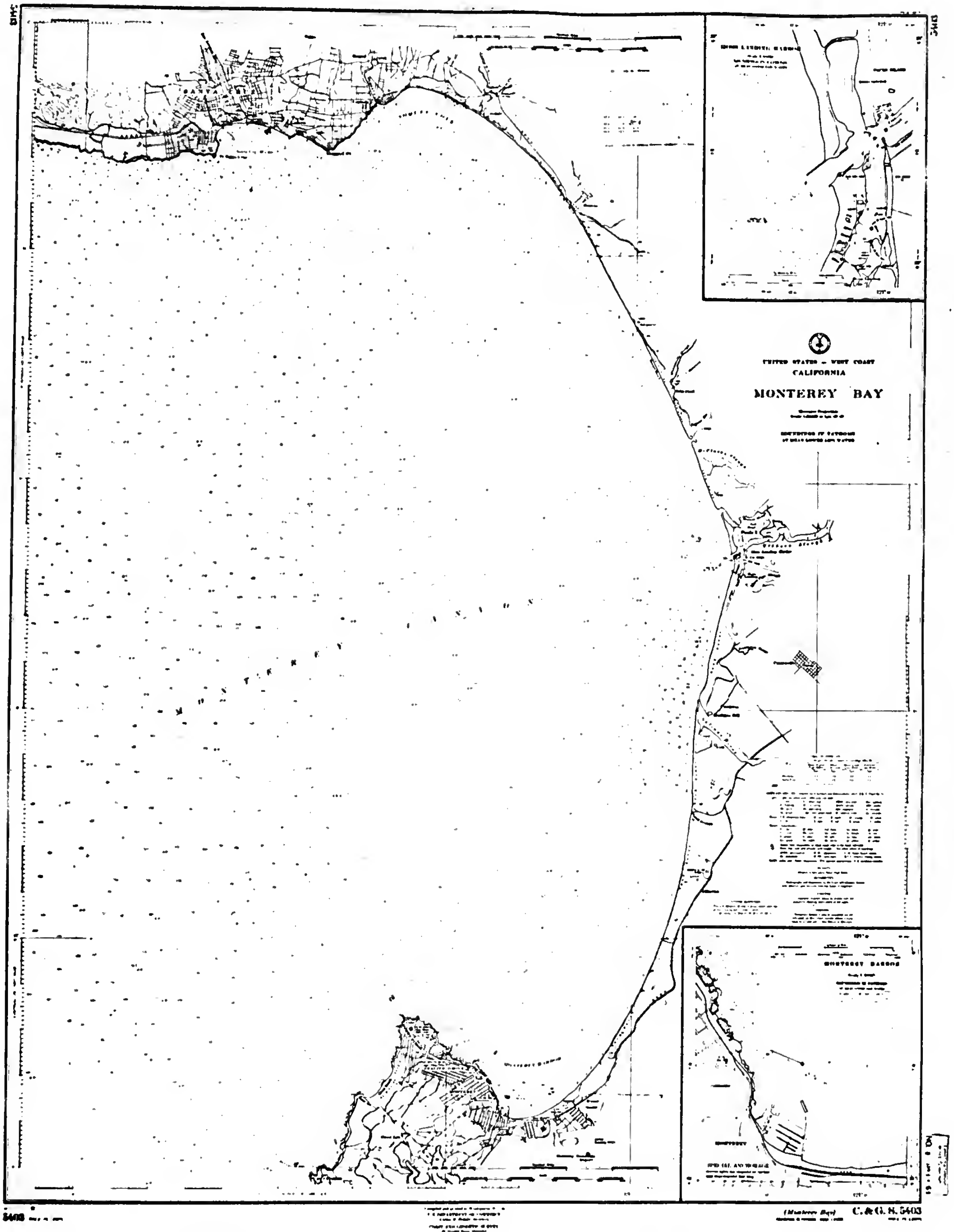


Figure 1. Chart of Monterey Bay.

This thesis problem was suggested to us by Professor W. C. Thompson of the Department of Meteorology and Oceanography, who provided much assistance and encouragement in all stages. In addition, we would like to express our thanks to all those who gave us help and without whose support this project could not have been accomplished. They include Captain W. H. Craven, Commanding Officer, U. S. Naval Air Facility, Monterey, California, who made helicopters available to us, and Lieutenant R. A. Rucks, USN, who piloted them; Commander R. W. Haupt, USN, and the men of the Departmental Library who assisted us in the early stages while testing the floats; Lieutenant J. A. Gould, USA, Commanding Officer of the 14th Transportation BARC Platoon, Fort Ord, California, who placed his vehicles at our service, and all his men who assisted us so ably and willingly throughout; Photographers Mate First V. O. McColly, USN, for his excellent photographic support; Mr. H. C. Green and the City of Monterey Engineer's Office for supplying advice and charts; and Mr. R. D. Loftus, Physical Science Aid at the USNPGS, for the many varied tasks which he performed.

2. Previous Field Observations.

Comparatively few field observations have been made of near-shore circulations off sand beaches and most of these were made in Southern California, primarily in and around Scripps Institution of Oceanography at La Jolla, California [1, 3, 4 and 5]. These have shown that the circulation in and near the surf zone appears cell-like and consists essentially of the mass transport of water toward the beach by wave currents, the resulting long-shore currents which flow parallel to the shore in the breaker zone, and rip currents which return the excess water to sea at intervals along the beach.

The net movement of water particles in the direction of the shoreward-advancing wave crests causes an inflow of water into the surf zone in the form of a diffuse wave current. Areas of wave convergence and divergence along the beach result in large and small transport into the surf zone, thus producing differential elevations which lead to longshore currents.

The direction and speed of longshore currents off a relatively uniform sand beach are known to be determined by two basic controlling factors, the direction and angle of wave approach, and the occurrence of convergence and divergence zones along the beach. Considering the first factor alone, when waves approach the shoreline at an angle, the resulting longshore current direction is determined by the component of the wave direction parallel

to the shore. The current speed varies directly with the angle of incidence, but is also affected by the period and height of the waves and the foreshore slope of the beach. An increase in wave height and beach slope generally leads to an increase of the current, whereas an increase in wave period leads to a decrease of the current.

The second factor results in the differential mass transport of water into the surf zone by the wave current along the beach due to wave refraction on the shelf offshore. In convergence areas, for example, the resulting higher waves will raise the water level locally so that a current will flow along the beach in both directions away from the convergence center. Where longshore currents are caused by both the angle of incidence and differential refraction along shore, the phenomenon that is the stronger can be expected to determine the direction, although the strength of the current may be reduced by the opposing effect.

At intervals along a sand beach, the longshore current turns abruptly seaward and flows through the surf zone as a rip current. These currents then diffuse in all directions where some of the water is brought back into shore by the wave current. In some instances feeder currents, which flow opposite to the predominant longshore drift, contribute water to the rip currents. Convergence of both the longshore and feeder currents at the base of a rip current produces a cellular type of circulation.

## 3. Beach and Wave Conditions in the Survey Area.

The surveys were carried out along a portion of a beach a little over one mile in length, running from the southern boundary of the USNPGS property at Sloat Avenue to the Seaside City Limit at the Laguna Grande outflow (Fig. 2). The selected beach is a segment of the long continuous sand beach in southern Monterey Bay that extends uninterrupted, except when interrupted seasonally at the Salinas River mouth, from Moss Landing to Monterey Harbor, where it ends against the rocky shoreline of the Monterey Peninsula. The sea floor off the beach studied slopes uniformly seaward and the bottom contours closely parallel the beach trend.

Southern Monterey Bay is distinctive from the standpoint of prevailing wave conditions. The extreme southern end is so deeply indented that the beach is sheltered from wind waves most of the time and swell predominates. In addition, refraction of waves arriving from all directions in deep water is so extreme that the crests approach the beach with breaker angles that are very small or negligible most of the time (Fig. 3). Also, increasing divergence of wave energy occurs toward the southern end of the bay due to refraction of nearly all swell arriving from the open ocean, and results in successively smaller breaker heights toward the south end of the beach.

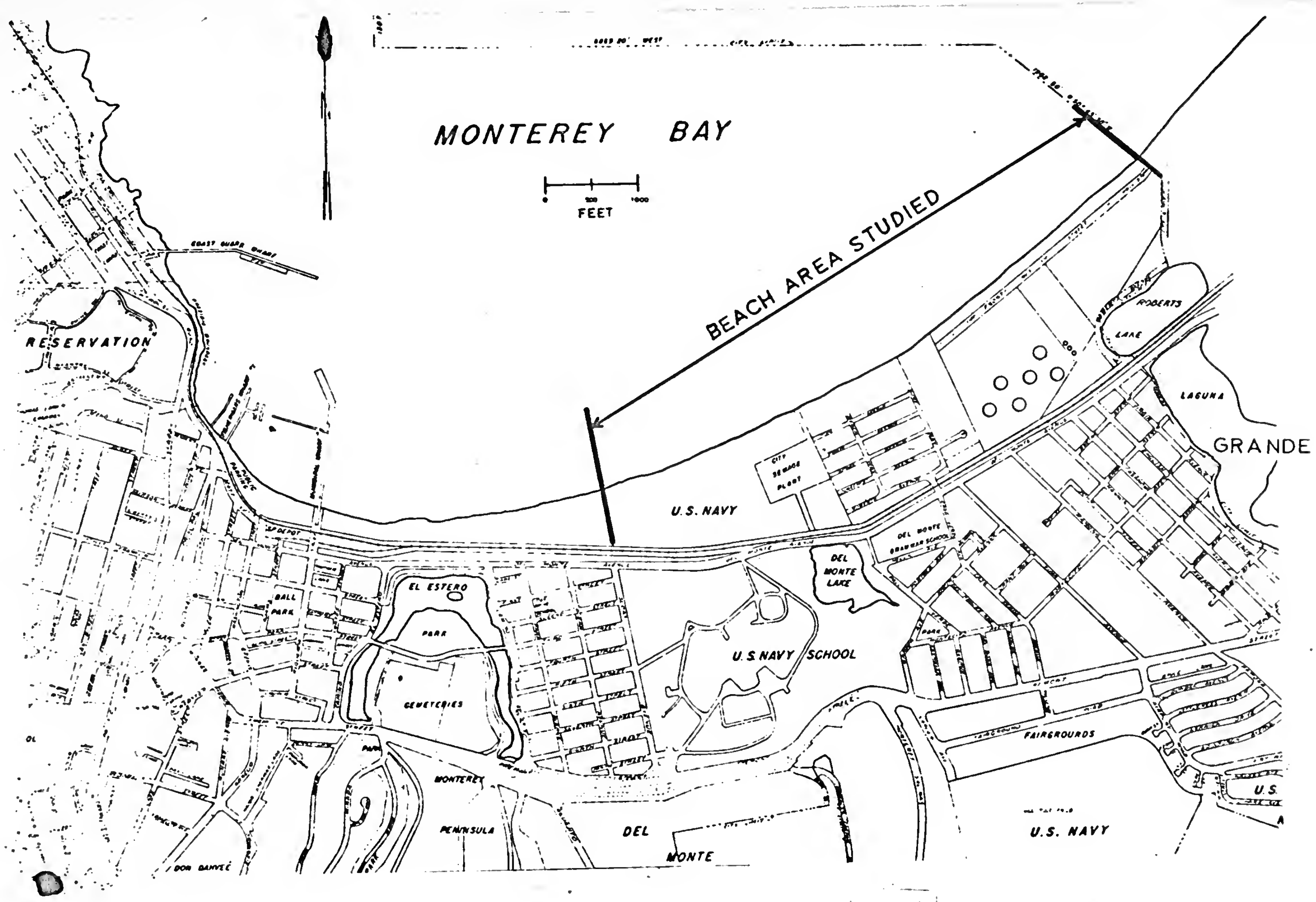


Figure 2. The Survey Area.

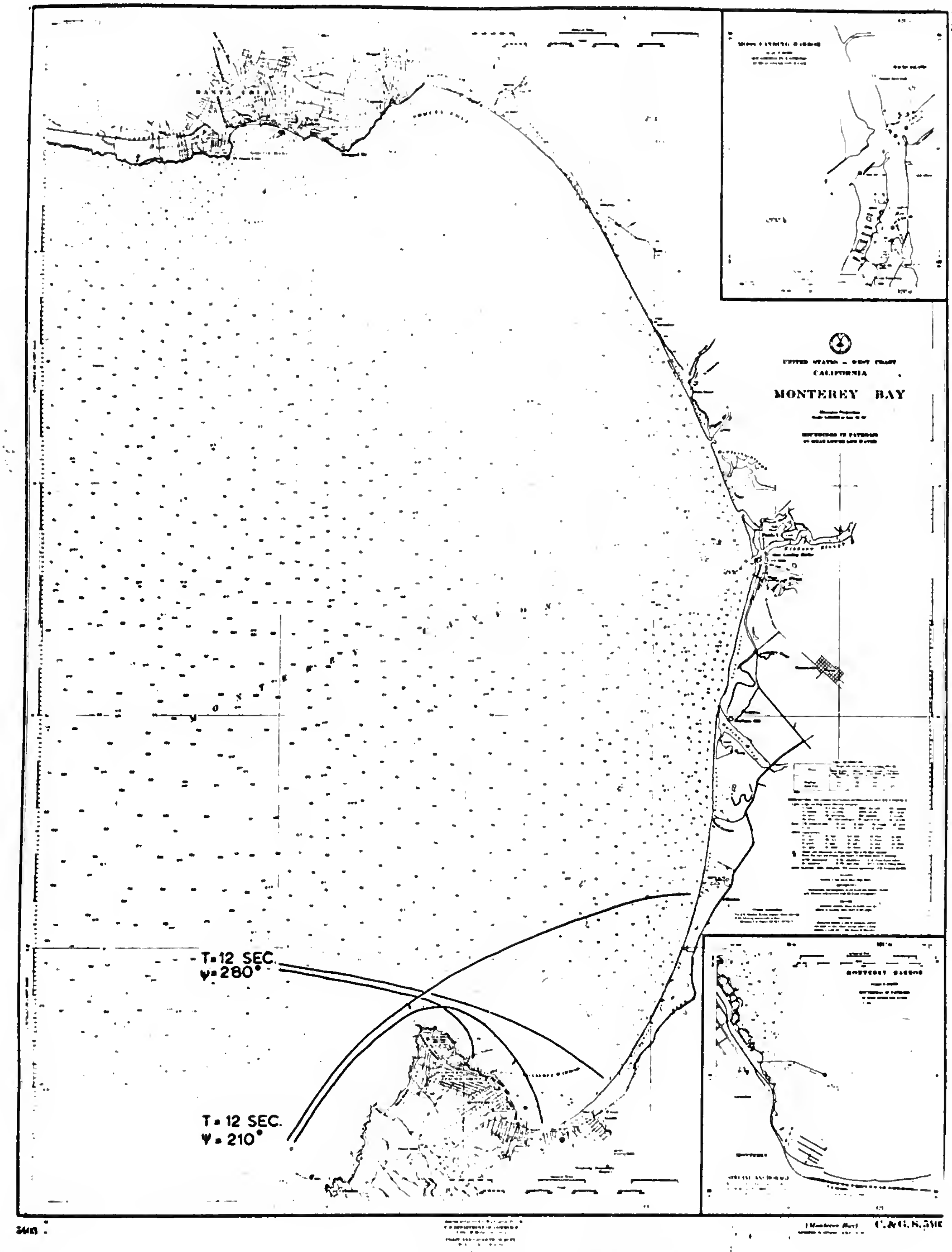


Figure 3. Examples of Wave Refraction. Orthogonals are shown for two sets of 12-second waves arriving from two directions in deep water.

As a result of these predominant wave conditions, a net longshore current associated with the breaker-height gradient along the beach should be directed toward the south, whereas a net longshore current related to the breaker angle should be directed toward the north. In addition, the characteristic average speed of the longshore current should be small due to the dominance of swell of small size. When considered all together, these factors suggest that the net longshore current is either very weak (and in a yet undetermined direction) or that it is absent. This deduction is supported by the observation that there has been no significant accretion or erosion of sand on the local beach as a result of construction of a bulkhead in 1962 alongside Monterey Municipal Wharf No. 2, located two-thirds of a mile to the south of the beach area studied. Furthermore, the beach has displayed no apparent change in position from examination of Coast and Geodetic Survey Charts dating back to the earliest survey of 1851 [2].

Although the net longshore current is negligible or absent, mass transport of water into the surf zone occurs with the swell. The frequent occurrence of rip currents observed on this beach indicates that they are a principal means of return of this water to the offshore area, and further indicates that localized longshore currents between the rip currents are common on this beach.

The dominance of swell and the absence of any appreciable net longshore current characterizes this beach as a natural laboratory in which circulation on the beach may be unique and may differ from the nearshore circulation patterns that have been observed on other beaches. Accordingly, the nearshore circulation along this beach merits study.

4. Survey Procedure.

a. Field Work.

It was decided to trace the nearshore circulation by the use of floats photographed from the air at known time intervals. Before the surveys began, the writers experimented extensively with a variety of types of floats in order to find a design that would best satisfy the requirements of this survey procedure. The principal requirements were that the floats accurately depict the surface currents and that they be readily visible in aerial photographs both seaward of and within the surf zone. The types of floats tested and their advantages and disadvantages are described in the Appendix.

The float that was selected for the surveys was devised by the writers and is illustrated in Fig. 4. It consisted of two automobile innertubes lashed together, the lower one being water-filled and the upper one air-filled and painted to enable good visibility from the air. Dye-marker packets were attached to each float for added visibility. A 40-foot motor launch owned by the USNPGS was used to test the various floats, but it was not used in the surveys that followed because of the hazard of its getting caught in a breaker while launching or retrieving floats a short distance seaward of the surf zone.

Figure 4. Double Innertube Floats.


Figure 5. Army BARC.

Figure 6. BARC Underway Just Seaward of a Breaker.

In the actual surveys, an Army BARC was used to launch and retrieve the floats. The BARC, shown in Figures 5 and 6, is a large amphibious vehicle, 65-feet long and weighing 100 tons. Its ability to retrieve floats in the surf zone after it had launched them and to travel onto and along the beach made it an invaluable craft for the task.

Each survey was carried out as follows: The floats were placed overboard from the BARC one after another in a line just seaward of the outermost breakers. It was anticipated that most or all of them would be carried into the surf zone, which proved to be the case. (A similar float deployment was used by Shepard and Inman [5] in an earlier field study in Southern California). Fourteen and 16 floats spaced approximately 400-feet apart were used in the first two surveys, and 25 to 30 floats spaced at about 200-foot intervals were used in the last three. Supplementary redwood boards and single dye-packet floats were used in the first two surveys only and were discontinued after they proved difficult to locate. In each survey, two different colors for the floats were used so that adjacent floats were different in color. This facilitated the identification of individual floats in the aerial photographs.

A Navy helicopter made successive passes over the beach at an altitude of 300 feet and at a speed of 60 knots at measured intervals of one to six minutes, from which oblique photographs were taken using 35mm color film. Experimentation showed it was best to take the photographs over the water looking toward the beach, as topographic and man-made features on the beach, which served to orient each photo, were more readily apparent. The overlap in the photographs helped identify individual floats and to fix their positions in relation to one another and to known objects on the beach. Eight to 12 photographs were taken on each pass along the beach by the helicopter, and 5 to 18 passes were made during each survey. The time required to conduct each survey was between 20 and 40 minutes, whereas the preparation time for each survey was about four hours and involved considerable coordination between the helicopter, BARC, and personnel on the beach.

b. Plotting Procedure.

In order to assimilate the data from a given survey into a usable form, the 35mm slides were projected onto a screen, the floats were located and identified, and their positions were transferred to a work chart of scale of 1:1200. The locations of all circulation features noted in the photographs were also plotted on the work charts, such as rip currents and dye trails. A portion of the work chart from Survey No. 4 is shown in Fig. 7. In the figure, the dashed lines extending from individual floats represent elongate trails of dye emanating from the float.

The positions of the floats and circulation features could not be plotted on the work charts exactly because of errors inherent in the transfer of data from the oblique photographs to the chart due to parallax in the photos. However, because the photographs were taken looking shoreward it was possible to fix positions reasonably accurately from the many land features evident in the slides, such as poles, streets, fencelines, pipelines, tanks, and painted beach markers. These features were so numerous that it is estimated the lateral or along-shore position of each float was determined to within five feet of its actual position. In determining the distance of the floats from shore, the effects of parallax were much harder to overcome due to the

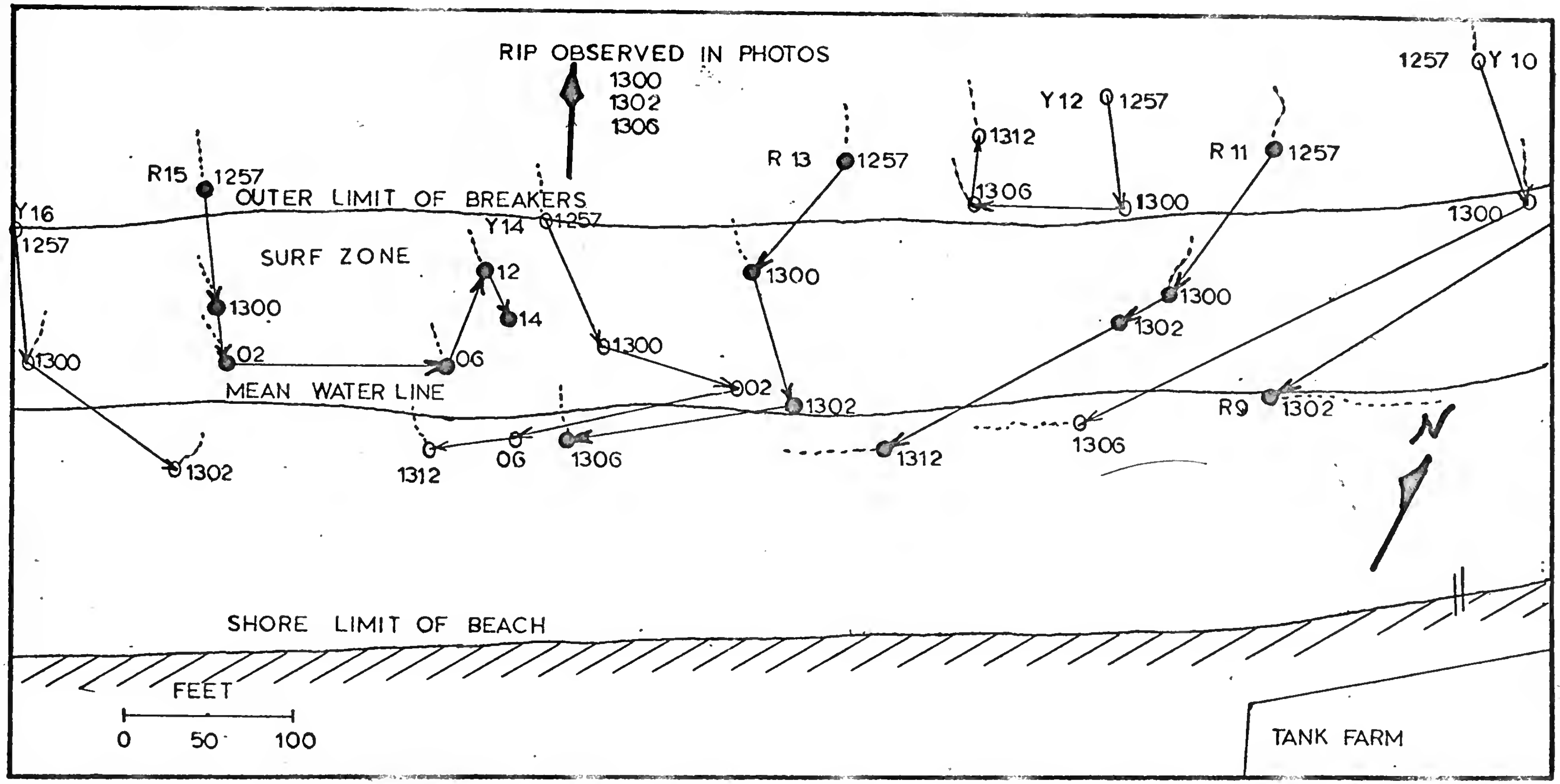


Figure 7.. A Portion of the Work Chart for Survey Four.

lack of adequate references in and near the water. By using the known width of the beach (at known tide stages), the estimated surf-zone width, the dimensions of the BARC (when present in the pictures), and a few other features of known size, it is estimated the offshore-onshore position of each float was established to within 20 feet of its true position. In addition, three or four floats were ordinarily present in each slide so that their relative positions also aided in fixing their true positions. After the successive positions of each float were plotted, their speeds were found by measuring the distance between the successive plots and dividing by the time interval. The times assigned to each plotted position were accurate to within 15 seconds.

In examining the slides, long, narrow dye trails were observed to extend away from many of the floats as far as 100 feet in several cases. If the floats and the water moved exactly together, a roughly circular dye patch would be expected around each float due to normal eddy diffusion. The existence of elongate dye trails indicates shear between the float and the water, for which two explanations may be offered. One possibility was that the upper innertube offered a sail area to the wind so that some wind effect was probably experienced by the float. Another possible explanation is that vertical shear in the upper few inches

of the water under the stress of the wind may also have carried away a thin surface layer of dye from the more deeply embedded float. No estimate was made of the relative importance of the wind stress exerted on the float to the water resistance; however, the fact that in spite of the direction of the wind, the floats travelled in a variety of directions in the surf zone leads to the conclusion that wind effect was not very important, and that the floats accordingly reflected the water circulation in the surf zone quite closely.

The work charts for each survey are very long and narrow so that they could not easily be included in this thesis; therefore schematic charts in which the width of the surf zone has been expanded were prepared for presentation. These charts are shown in Figures 8 through 12, and represent the results of this study.

5. Observed Circulation Patterns.

The nearshore surface water circulations prevailing during each of the five field surveys are shown in Figures 8 through 12. In each schematic diagram the beach is marked at 400-foot intervals for the purpose of describing the locations of floats, rip currents, and other circulation features. The tracks followed by the individual floats are indicated by irregular trajectories. Current speeds along each trajectory are variable and are not shown.

The positions of rip currents are shown by arrows directed seaward. The rip currents were lettered alphabetically from the south toward the north independently in each survey. If a rip current was definitely apparent in successive slides or indicated by the plotted float trajectories, it is shown by a solid shaft, but if the rip current only occurred briefly, a dashed shaft is shown to indicate its temporary existence. Though the beach has a NE-SW orientation, all directions are referred to as simply north for northeast and south for southwest. All floats in all surveys were ultimately recovered on the beach.

In the pages to follow each survey is discussed individually and the circulation pattern is described with comments on the float trajectories and observed current speeds. A summary of the weather and sea conditions prevailing during each survey is presented in Table I following the survey descriptions.

A. Survey One (Fig. 8); 16 floats.

On the southern part of the beach (Stations 0-11), convergence and divergence of the float trajectories indicated a fairly good cellular circulation in the surf zone, although all floats came ashore more or less directly. Two floats were carried slightly seaward in rip currents before beaching. On the northern end of the beach the flow was predominately to the north, with the trajectories not indicating the presence of the two well-defined rip currents in that vicinity.

Eleven floats followed trajectories toward the north and five toward the south in traversing the surf zone. The five southward-moving floats were directly associated with rip currents that were evident in the photographs.

A total of seven distinct rip currents were observed. The three northernmost rips (E, F, and G) were separated by 1000 feet, whereas the five rips to the south were about 700 feet apart. No current speeds are available for this survey because the fly-over intervals of the helicopter were not recorded.

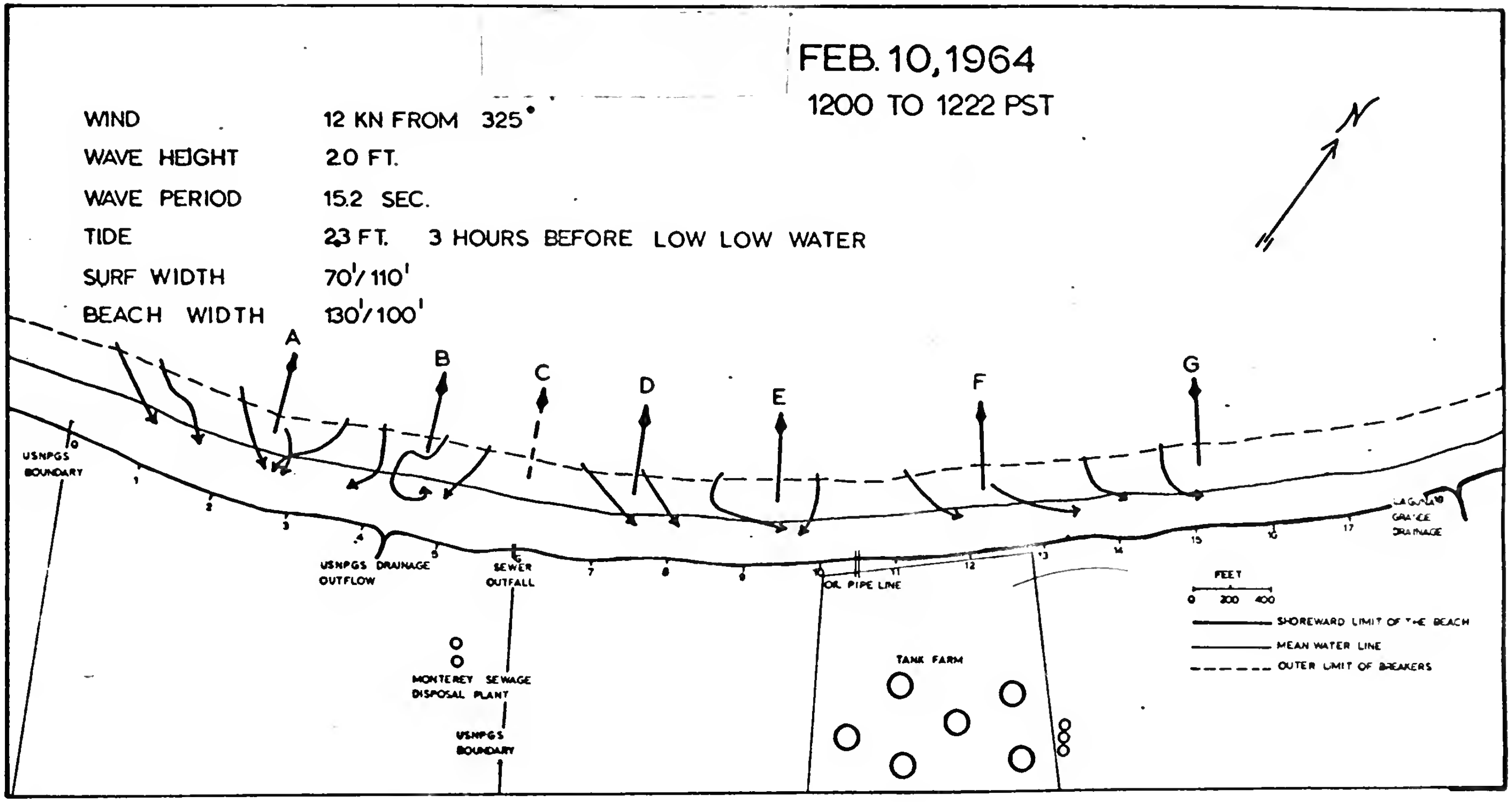


Figure 8. Chart of Survey One.

B. Survey Two (Fig. 9); 14 floats.

The general circulation tended to be cellular, with the overall flow being toward the north. Four rip currents were observed, being almost equally spaced at 1100 feet apart.

Nine floats moved northward and five went to the south. The southbound floats were all associated with rip currents. In two cases float trajectories passed shoreward of the rip currents and gave no indication of their presence; however, at the time of passage these rips were not observed in the photographs.

Between stations 0 and 10, the speeds of the floats through the surf zone as they approached the beach ranged from 50-130 ft/min, and decreased to 10-30 ft/min as they moved parallel to the beach after touching the beach face. Between stations 11 and 13 the opposite occurred, the floats travelling from 13-30 ft/min through the surf zone and 50-90 ft/min as they moved along the beach.

There was no southward flow between stations 11 and 13, and one float drifted persistently northward even after passing shoreward of Rip D.

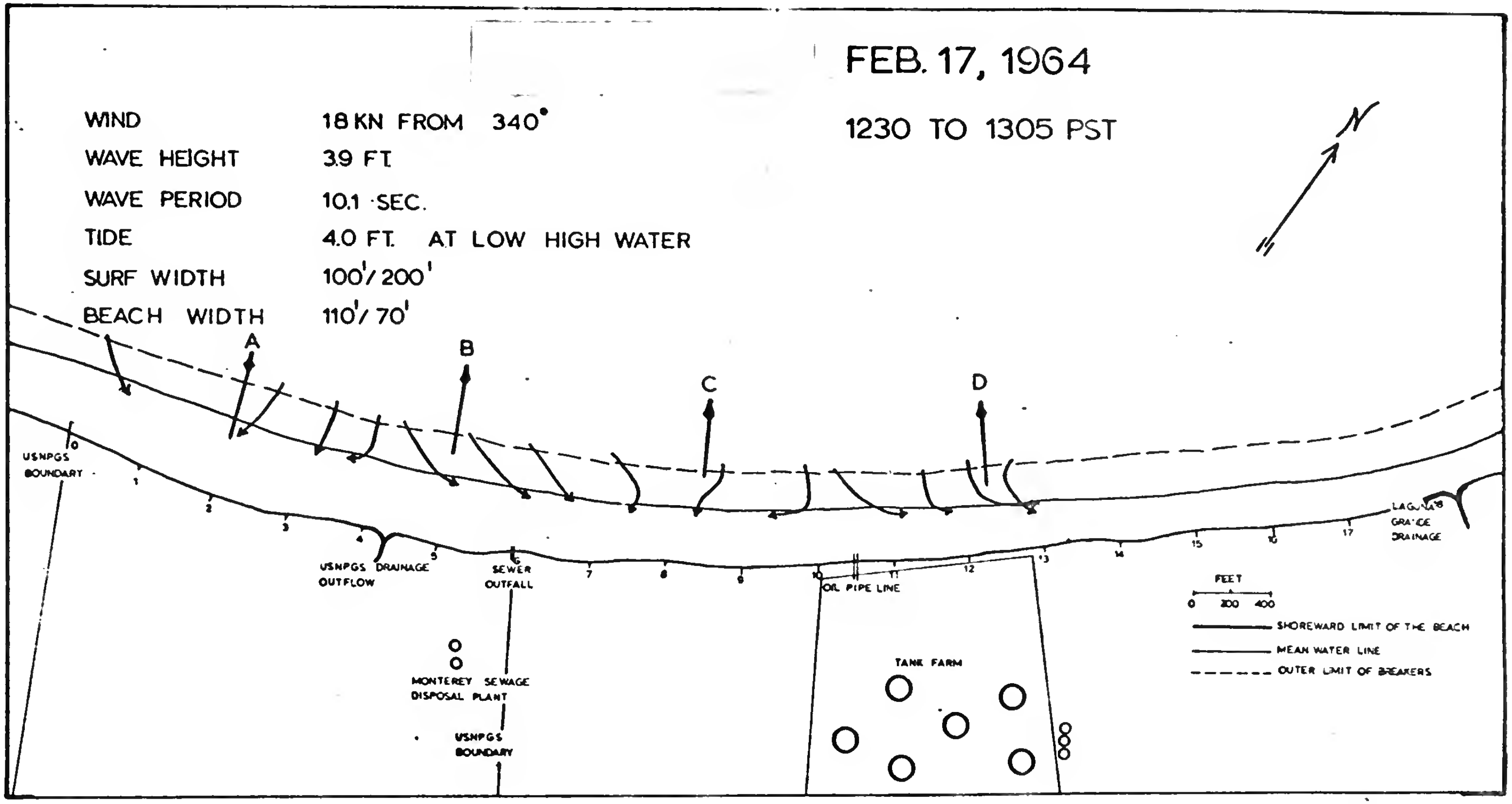


Figure 9. Chart of Survey Two.

C. Survey Three (Fig. 10); 30 floats.

Strong northward flow dominated along the entire beach as indicated by the extremely long float trajectories roughly paralleling the beach.

Four persistent rip currents were observed throughout this survey, with two additional rip currents appearing briefly during part of the time. Rip A was not observed in the photographs but was indicated only by the float trajectories. Rips A, B, and C, were 1200-1600 feet apart, while Rips C, D, E, and F were 500-800 feet apart. All rip currents, except Rip A, had considerable effect on most floats passing through them, with most of these being carried out from the beach but not far beyond the outer line of breakers. These floats moved northward, in some cases at relatively high speeds, and all ultimately beached. At the northern end of the beach the rip currents were stronger but no southward-moving feeder currents to the rip currents were detected.

Twenty-six floats moved to the north and four went south. The northerly trajectories were generally flat and long, extending up to 1500 feet along the beach, whereas the southerly tracks were much shorter and were associated only with well-defined rip currents. Two floats had trajectories involving considerable north and south movement.

One of these passed through Rip A with no apparent effects, but the other was caught in Rip B and moved offshore to seaward of the surf zone. The southernmost float travelled northward, passing to seaward and to landward of other floats that eventually beached before it did.

The speeds of individual floats varied markedly throughout the survey.

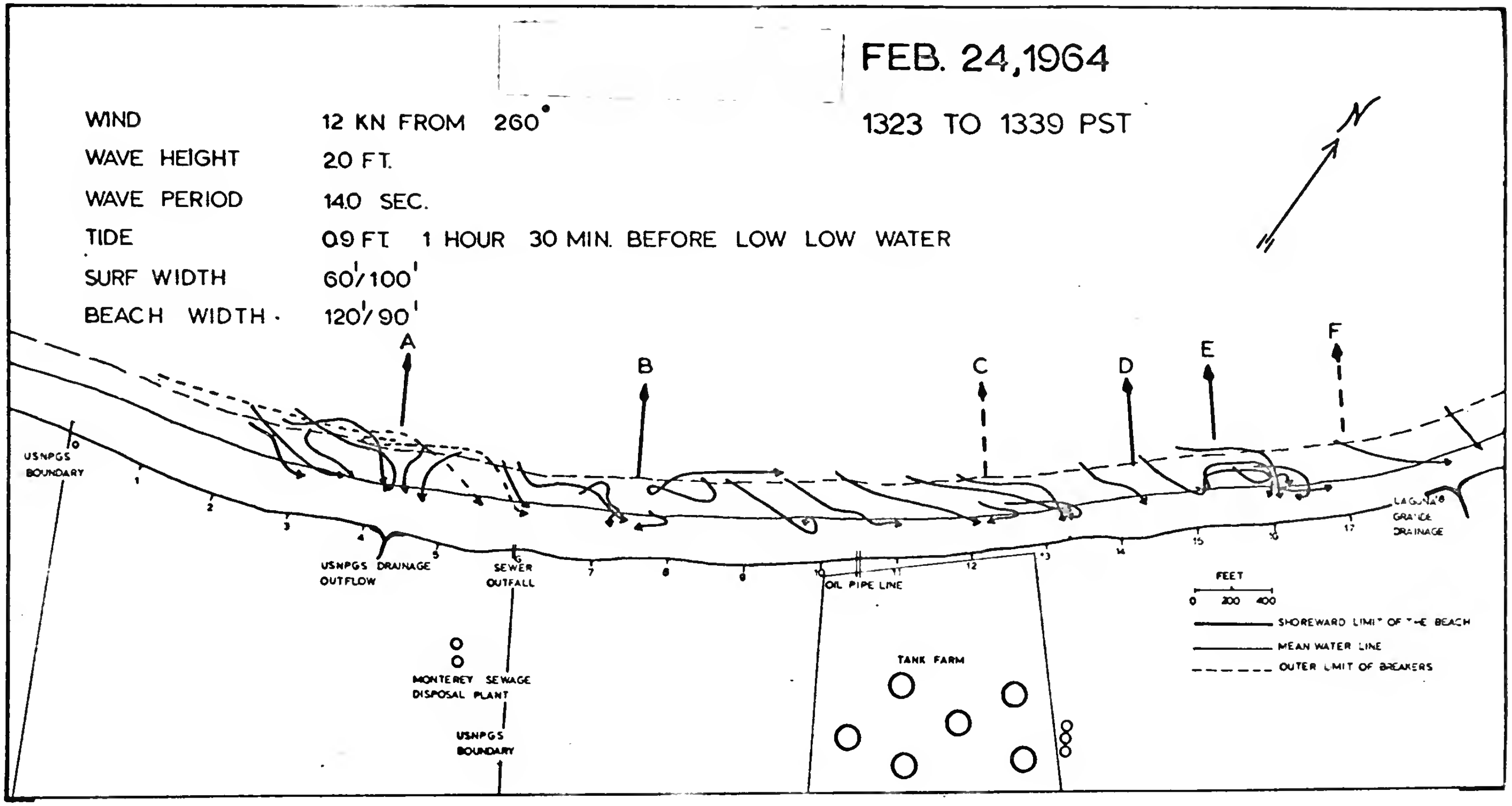


Figure 10. Chart of Survey Three.

D. Survey Four (Fig. 11); 25 floats.

The flow was dominantly to the north along the entire beach. The floats generally came into shore directly and did not travel far parallel to the beach. Only two rip currents were observed, near the center of the survey area (stations 10 and 13), and these affected the floats locally. Two floats were caught in Rip A and moved seaward but not beyond the outer breakers. No trajectories were especially unusual.

Float speeds were fairly uniform along the entire beach, both seaward of and within the surf zone, and ranged from 25-40 ft/min. Speeds in the rip currents, obtained from floats moving away from the beach, were about 10 ft/min. Floats grounding on the sand traveled at 15 ft/min along the beach.

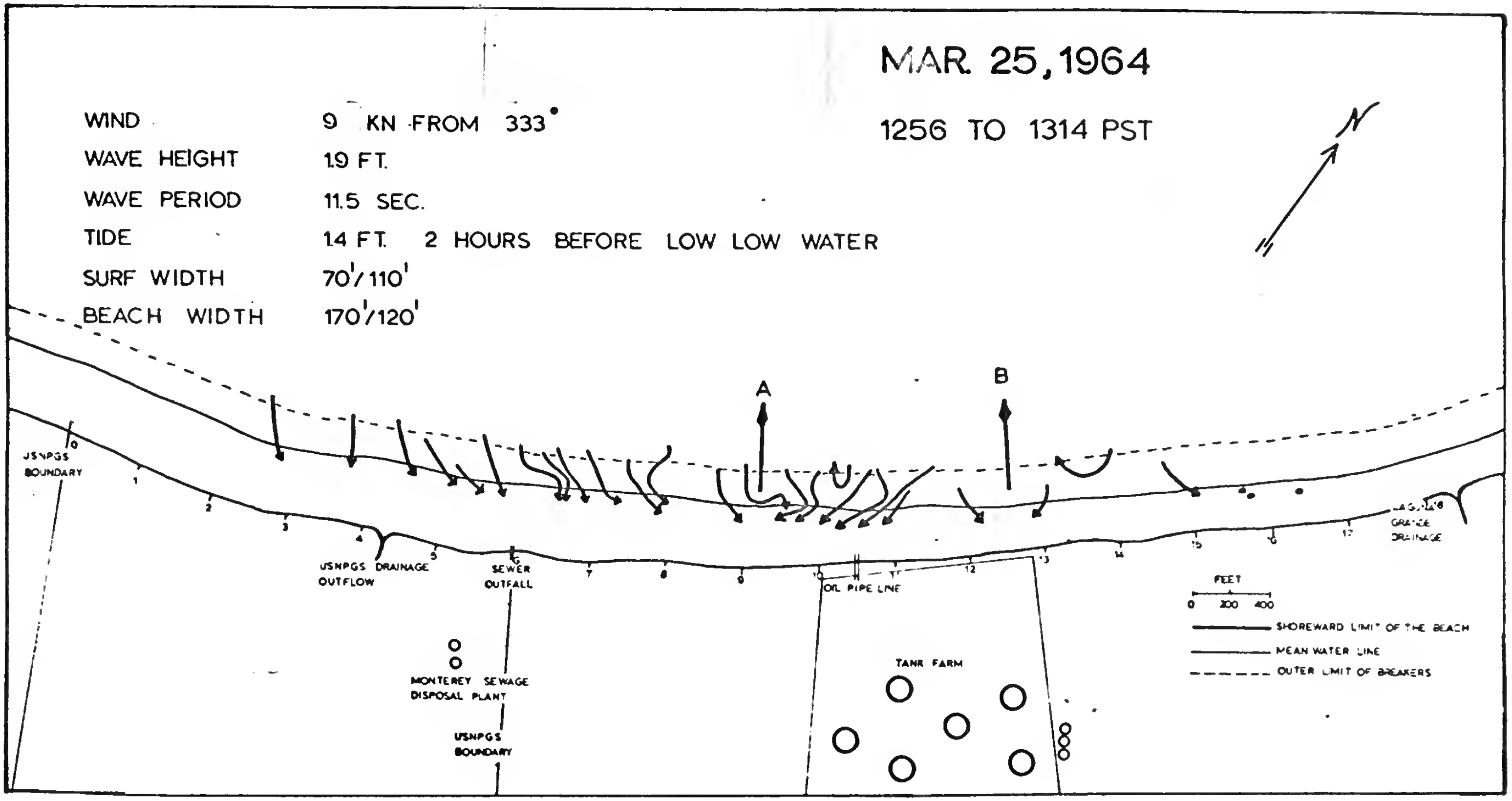


Figure 11. Chart of Survey Four.

E. Survey Five (Fig. 12); 25 floats.

This and the preceding survey were conducted on the same day about one hour apart. Survey Five covered an additional 1500 feet of beach at the northern end. This extension disclosed two distinct rip currents in that area. This survey also showed a weak rip current off station four that did not occur in the previous survey. The two rip currents appearing in Survey Four were also present in Survey Five. Thus, Survey Five had four strong rip currents, and one that was apparent only in the trajectory plots and not in the photographs.

Northward flow predominated as in the earlier survey; however, the circulation was more cellular in nature all along the beach. Two floats were carried seaward but they were not carried far beyond the outer line of breakers and eventually beached of their own accord. As in Survey Four, the floats generally did not parallel the beach for any distance but tended to beach rapidly.

All floats moved northward except three which had distinct southward tracks. The latter were all directly associated with one of the rips. Speeds of the rip currents were about 10 ft/min, whereas the floats moving into the beach drifted at 10-30 ft/min.

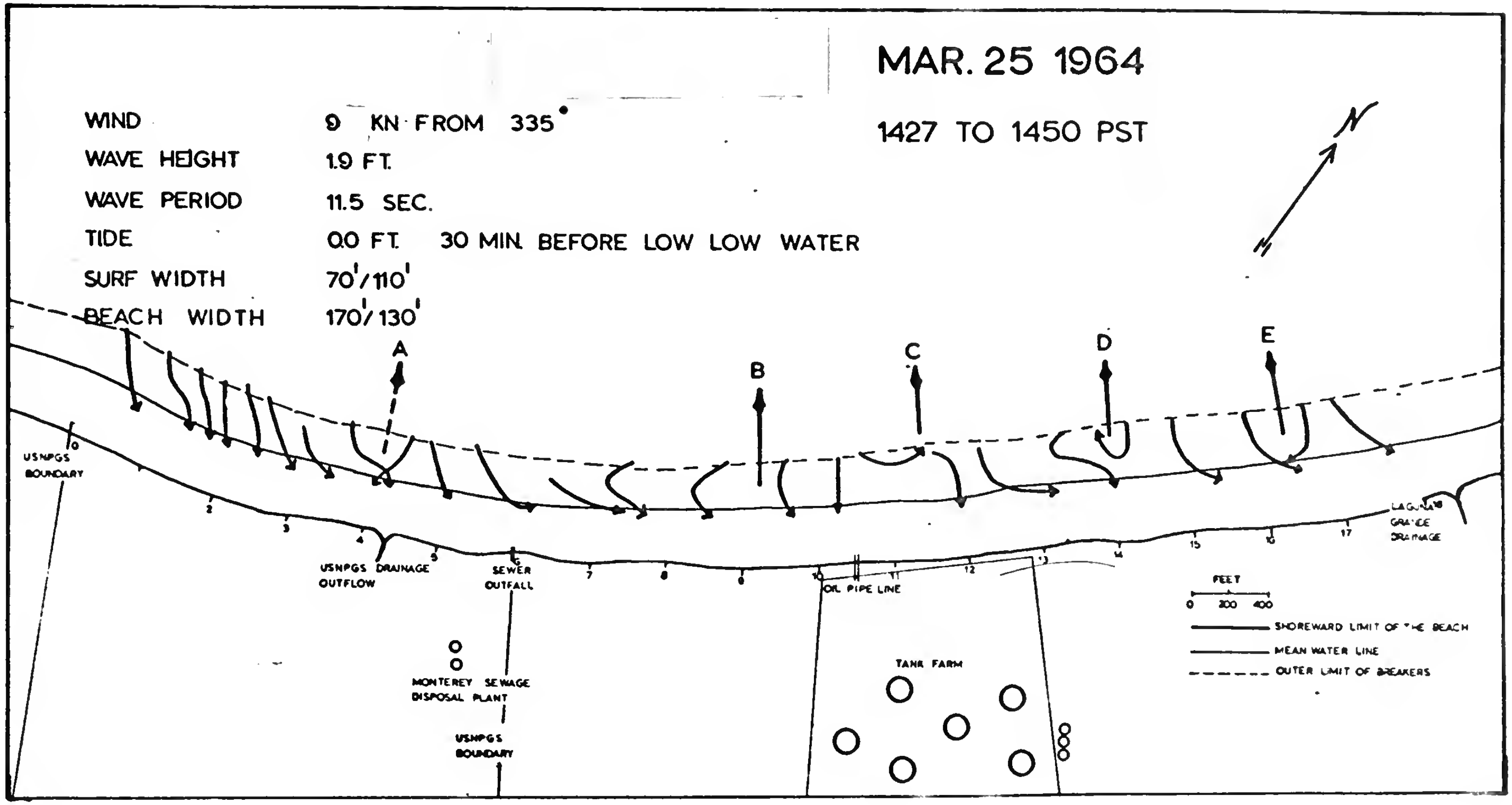


Figure 12. Chart of Survey Five.

Table I: Summary of Weather and Sea Conditions Prevailing During Each Survey.

| Survey Number | Date | Wind | | Breakers | | Surf Width | Tide* |
|---|---|---|---|---|---|---|---|
| | | Speed | Direction | Height | Period | | |
| 1 | 10 Feb 64 | 12 kn | 325 deg. | 2.0 ft. | 15.2 sec | 70 to 110 ft. | 2.3 F |
| 2 | 17 Feb 64 | 18 | 340 | 3.9 | 10.1 | 100 to 200 | 4.0 LHW |
| 3 | 24 Feb 64 | 12 | 260 | 2.0 | 14.0 | 60 to 100 | 0.9 F |
| 4 | 25 Mar 64 | 9 | 333 | 1.9 | 11.5 | 70 to 110 | 1.4 F |
| 5 | 25 Mar 64 | 9 | 335 | 1.9 | 11.5 | 70 to 110 | 0.0 F |

* The tide height is in feet relative to an arbitrary datum.

Symbols: F means falling, LHW means Lower High Water.

6. Analysis of the Observed Currents.

The distances travelled by each float in known time intervals were available from the work sheets for each survey (see example in Figure 7). This yielded a considerable number of current measurements. These individual current increments were analyzed in terms of their onshore-offshore components and their north-south components parallel to the beach.

The onshore component can be considered to give a measure of the speed of the incoming wave current at the surface, and the offshore component to represent rip currents. Since in all surveys the dominant flow was to the north, the northward component gives a measure of the dominant longshore current that prevailed, and the southward component represents the local feeder currents to the rip currents.

In order to obtain a comparison between the current velocities outside the breakers with those in the surf zone, it was decided to group the various tracks on the basis of whether the unit trajectories lay outside the surf zone, astraddle the outer breaker line (transition zone), or within the surf zone. Histograms were then prepared of the current speeds in the areas outside and inside the surf zone, and these are presented in Figures 13 through 22 for Surveys Two through Five (no current speeds are available for Survey One). As the wind and wave conditions were similar during all of the surveys, composite histograms were prepared by combining all the data, and these composites are shown in Figures 13 and 18. From the data presented in the histograms, frequency-

weighted mean values of the current components were computed, and are tabulated in Table II for the offshore zone, the transition zone, and the surf zone. Also tabulated in the table (the figures in parentheses) are the number of observations on which the mean current speeds are based; these give a measure of the frequency of the observations in the four directions. The maximum current speeds in each category are tabulated in Table III.

From examination of the histograms and tables, it may be seen that outside the surf zone an onshore drift was dominant, but some weak offshore flow also occurred. In Survey Three,however, the rip currents were stronger than in the other surveys and approximated the onshore currents, although their frequency was definitely lower, There was no significant north-south drift seaward of the surf zone in any survey except Survey Three. The wind was somewhat different in direction (from the west) during that survey and it accordingly induced a flow to the north.

Inside the surf zone, northerly flow dominated in all surveys although there were some weaker southerly feeder currents associated with many of the rip currents. The speed of the offshore or rip-current flow was less than the onshore flow in each case, except for Survey Three where the rip-current speed was a little greater. Also in that survey, the southerly feeder currents associated with the rips were stronger.

Table II. Mean Current Speed Components and Frequency of Observations.

All speeds are in ft/min and numbers in parentheses are the frequency of observations.

| | Offshore | Onshore | South | North |
|---|---|---|---|---|
| Survey Two | | | | |
| Outside | 0.0 (0) | 23.0 (4) | 14.0 (2) | 4.0 (1) |
| Transition | 0.0 (0) | 20.0 (1) | 0.0 (0) | 10.0 (1) |
| Inside | 0.0 (0) | 24.5 (22) | 22.8 (10) | 40.4 (15) |
| Survey Three | | | | |
| Outside | 6.5 (8) | 10.9 (14) | 62.0 (2) | 41.2 (30) |
| Transition | 21.3 (2) | 20.4 (12) | 16.0 (1) | 28.8 (11) |
| Inside | 10.9 (15) | 9.0 (37) | 25.6 (12) | 22.4 (48) |
| Survey Four | | | | |
| Outside | 4.0 (1) | 20.0 (5) | 0.0 (0) | 6.8 (3) |
| Transition | 0.0 (0) | 30.4 (9) | 34.4 (5) | 16.0 (3) |
| Inside | 4.0 (1) | 17.4 (9) | 23.2 (8) | 23.2 (21) |

(Continued on next page)

Table II (Continued).

| | Offshore | Onshore | South | North |
|---|---|---|---|---|
| Survey Five | | | | |
| Outside | 4.0 (3) | 12.0 (4) | 56.0 (1) | 10.0 (4) |
| Transition | 0.0 (0) | 17.2 (7) | 0.0 (0) | 15.6 (7) |
| Inside | 8.0 (2) | 15.4 (36) | 15.6 (8) | 32.4 (30) |
| Composite | | | | |
| Outside | 4.8 (12) | 14.5 (27) | 43.2 (5) | 33.6 (38) |
| Transition | 21.3 (2) | 23.7 (29) | 31.2 (6) | 15.9 (22) |
| Inside | 10.2 (18) | 15.6 (124) | 22.4 (38) | 28.0 (114) |

Table III. Maximum Current Speeds (ft/min).

| | Survey Number | Component Directions | | | |
|---|---|---|---|---|---|
| | | Offshore | Onshore | South | North |
| Outside Surf Zone | 2 | 0 | 44 | 20 | 168 |
| | 3 | 20 | 44 | 120 | 100 |
| | 4 | 4 | 28 | 44 | 60 |
| | 5 | 4 | 24 | 44 | 360 |
| | Composite | 20 | 44 | 120 | 360 |
| Inside Surf Zone | 2 | 0 | 56 | 100 | 180 |
| | 3 | 20 | 44 | 28 | 100 |
| | 4 | 4 | 44 | 44 | 60 |
| | 5 | 12 | 52 | 44 | 52 |
| | Composite | 20 | 56 | 100 | 180 |

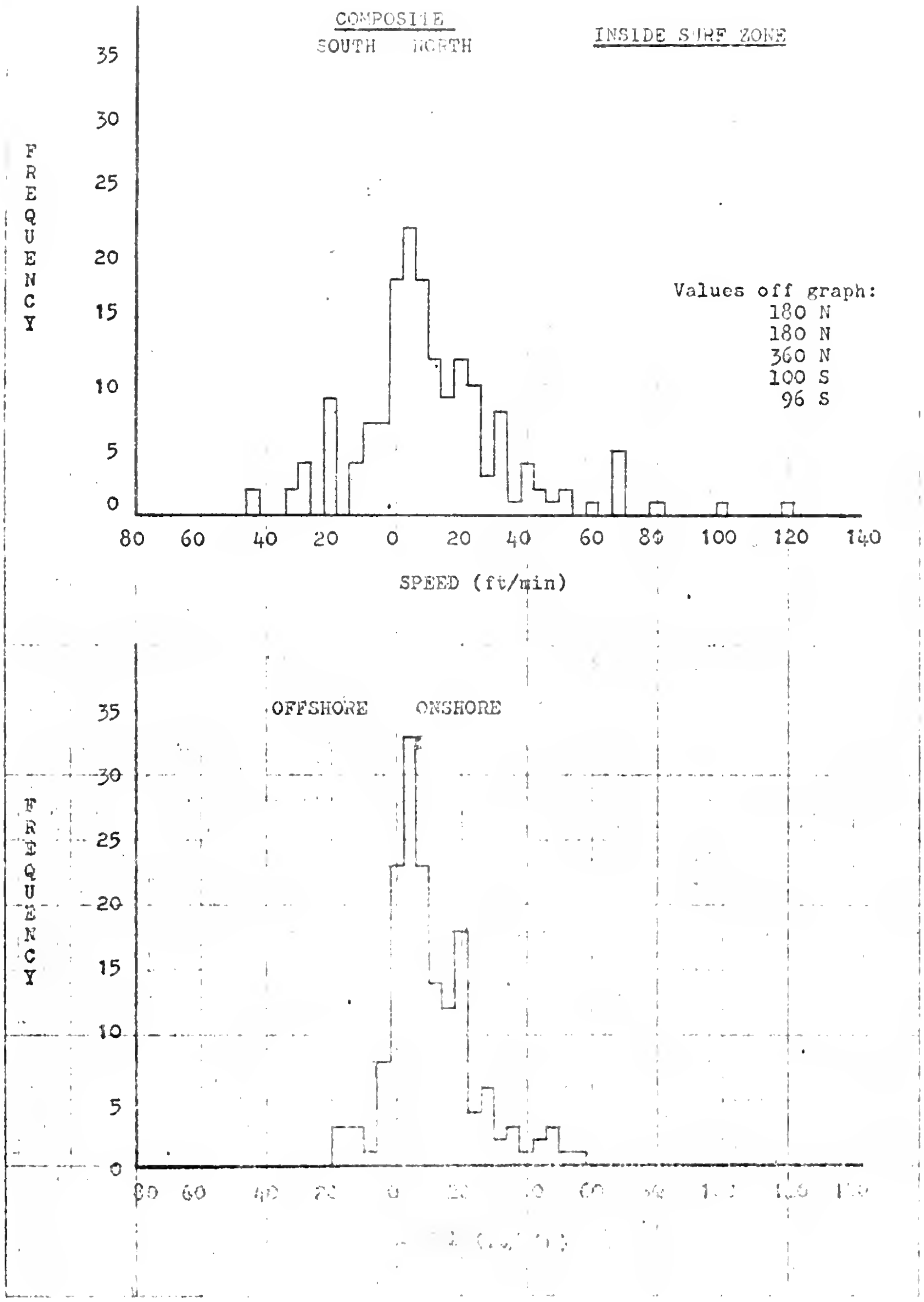


Figure 13. Current Components Inside Surf Zone, Composite.

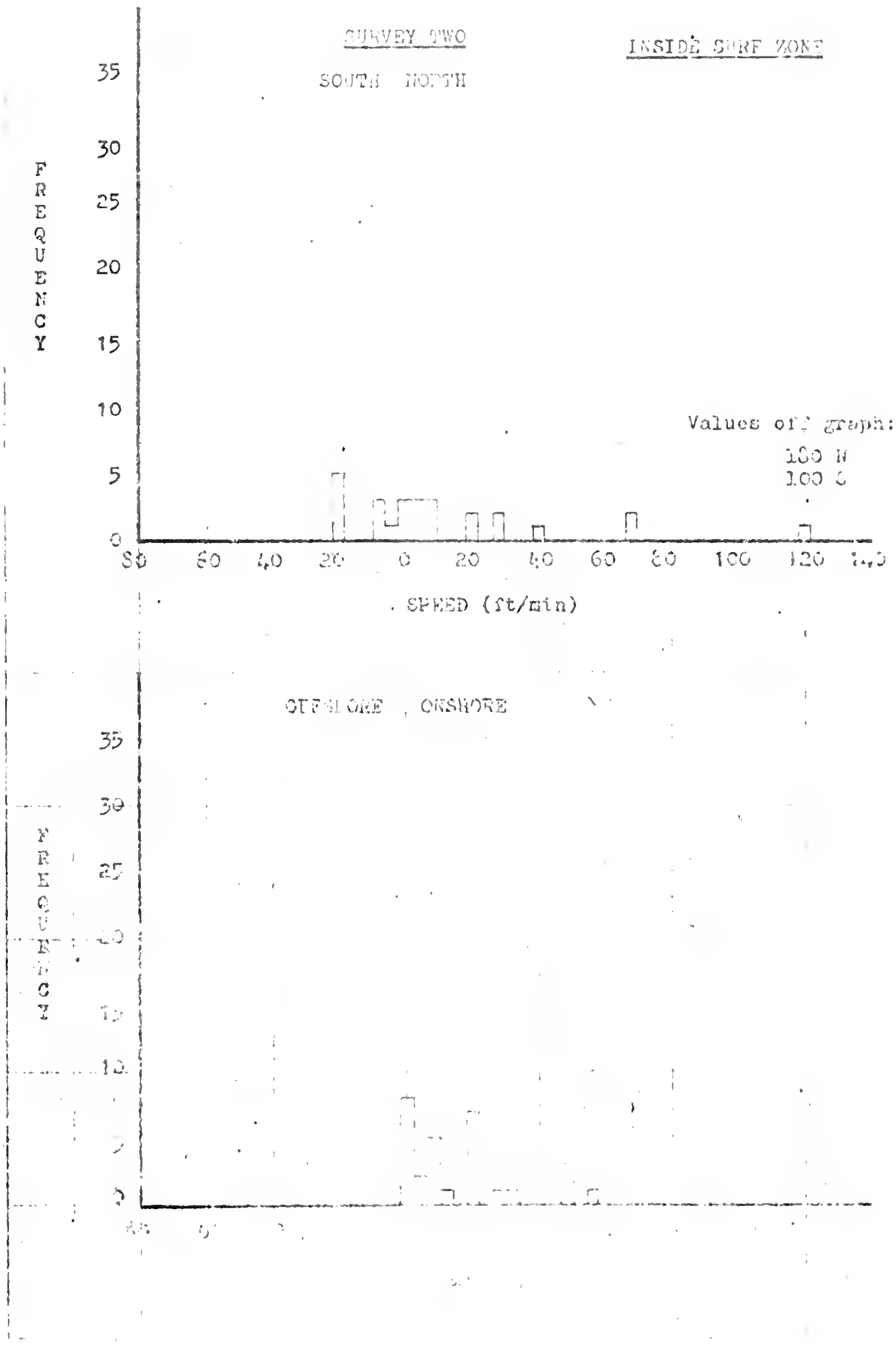


Figure 14. Current Components Inside Surf Zone, Survey Two.

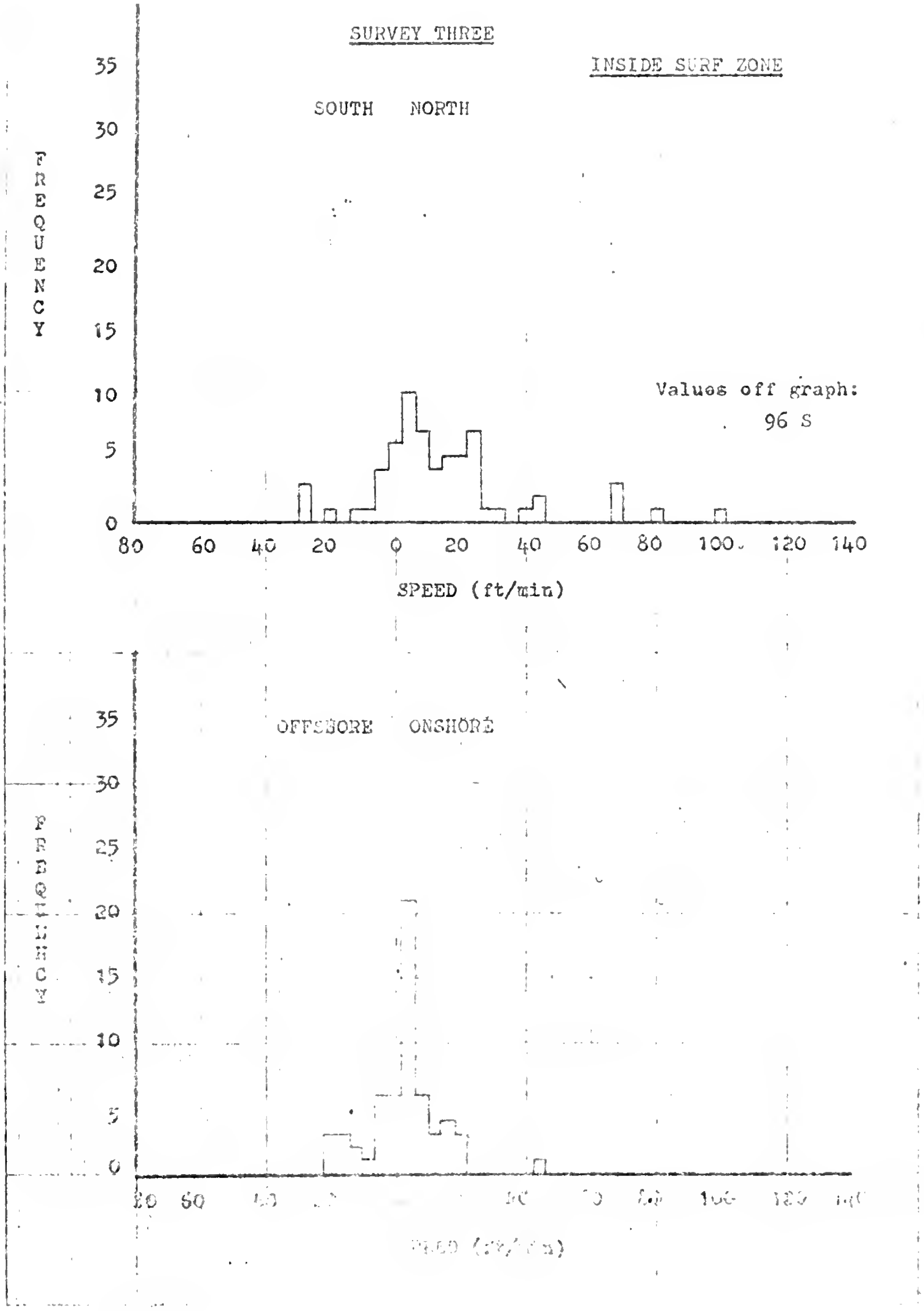


**Figure 15. Current Components Inside Surf Zone, Survey Three.**

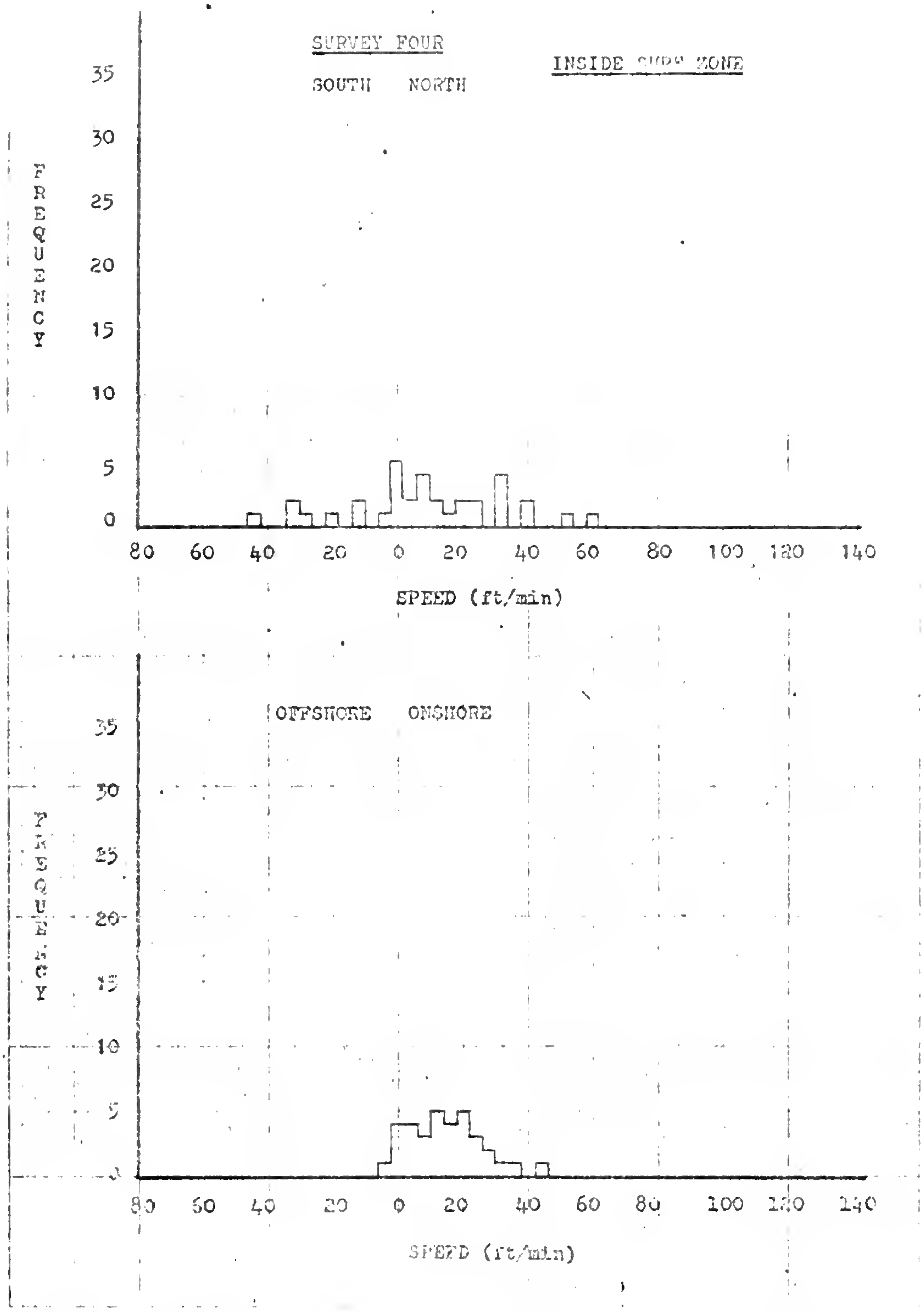


**Figure 16. Current Components Inside Surf Zone, Survey Four.**

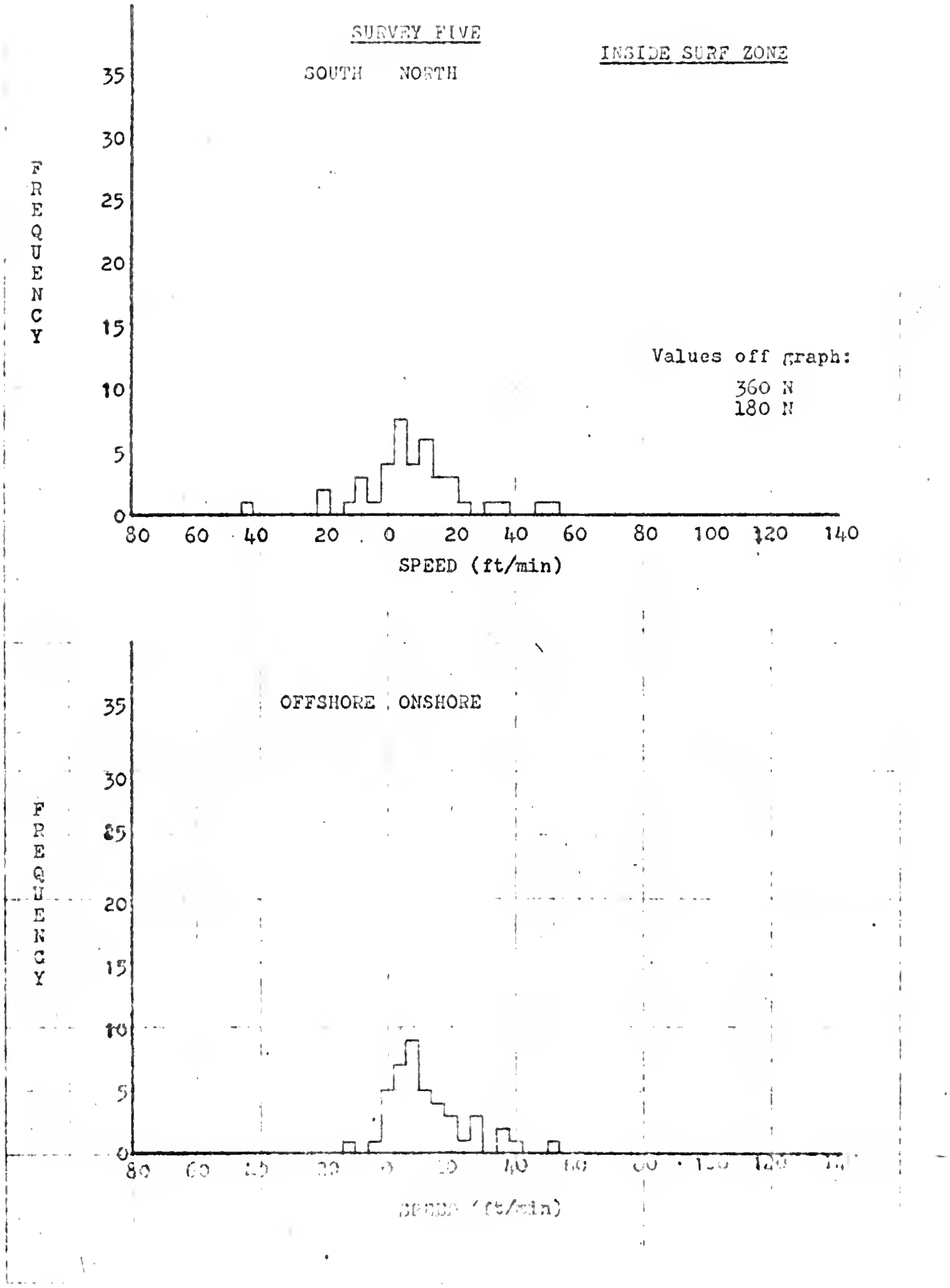


**Figure 17. Current Components Inside Surf Zone, Survey Five.**

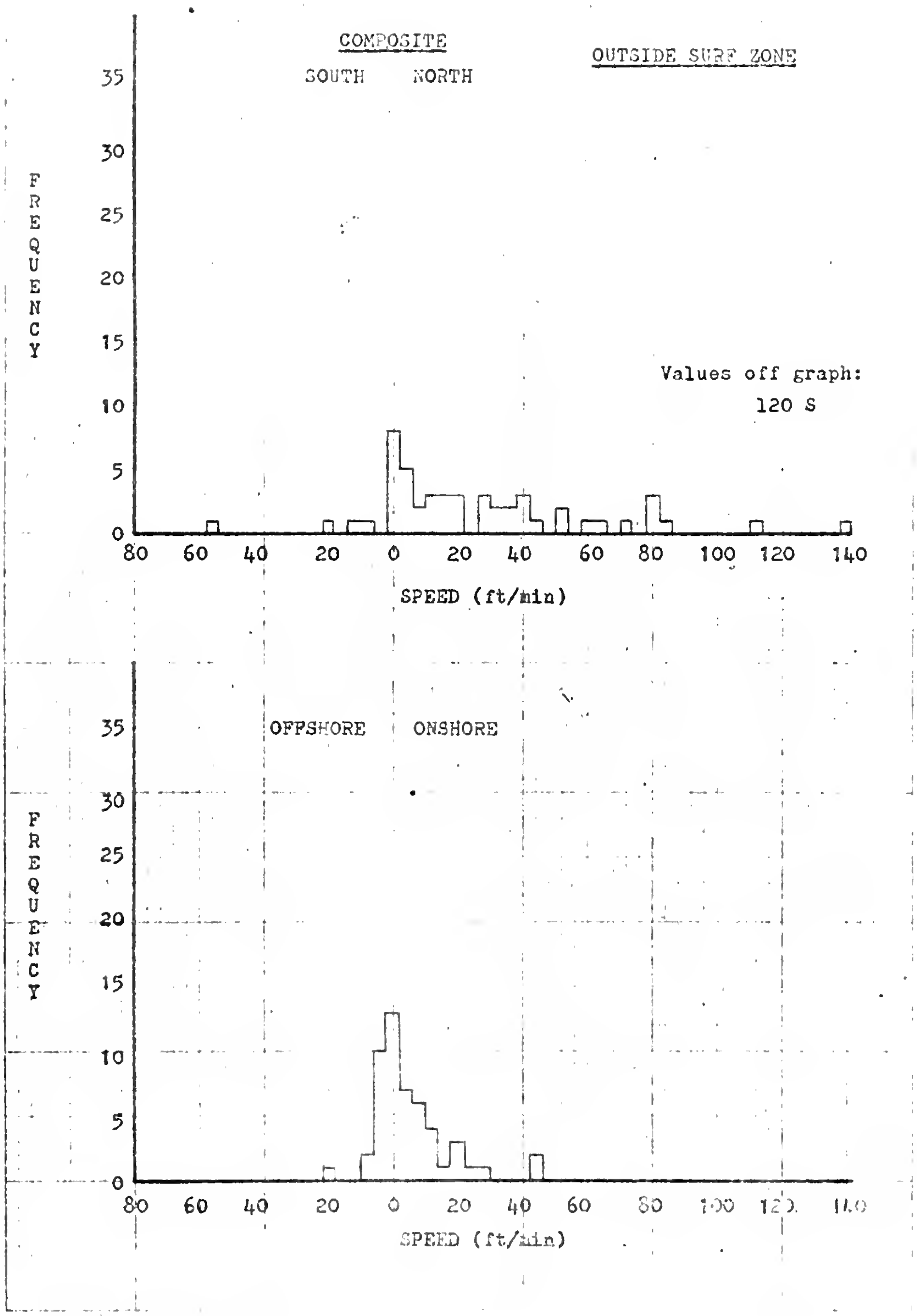


**Figure 18. Current Components Outside Surf Zone, Composite.**

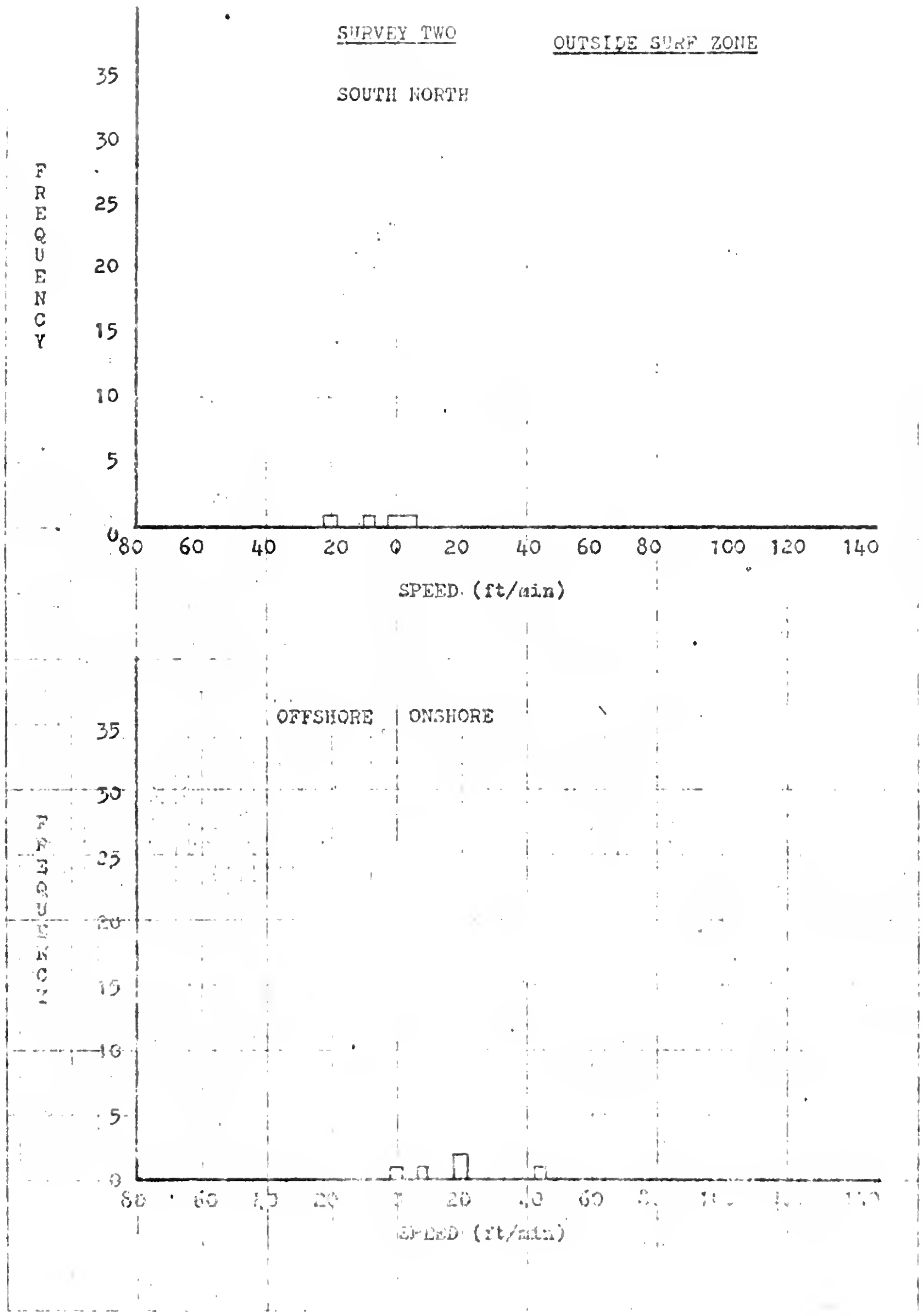


**Figure 19. Current Components Outside Surf Zone, Survey Two.**

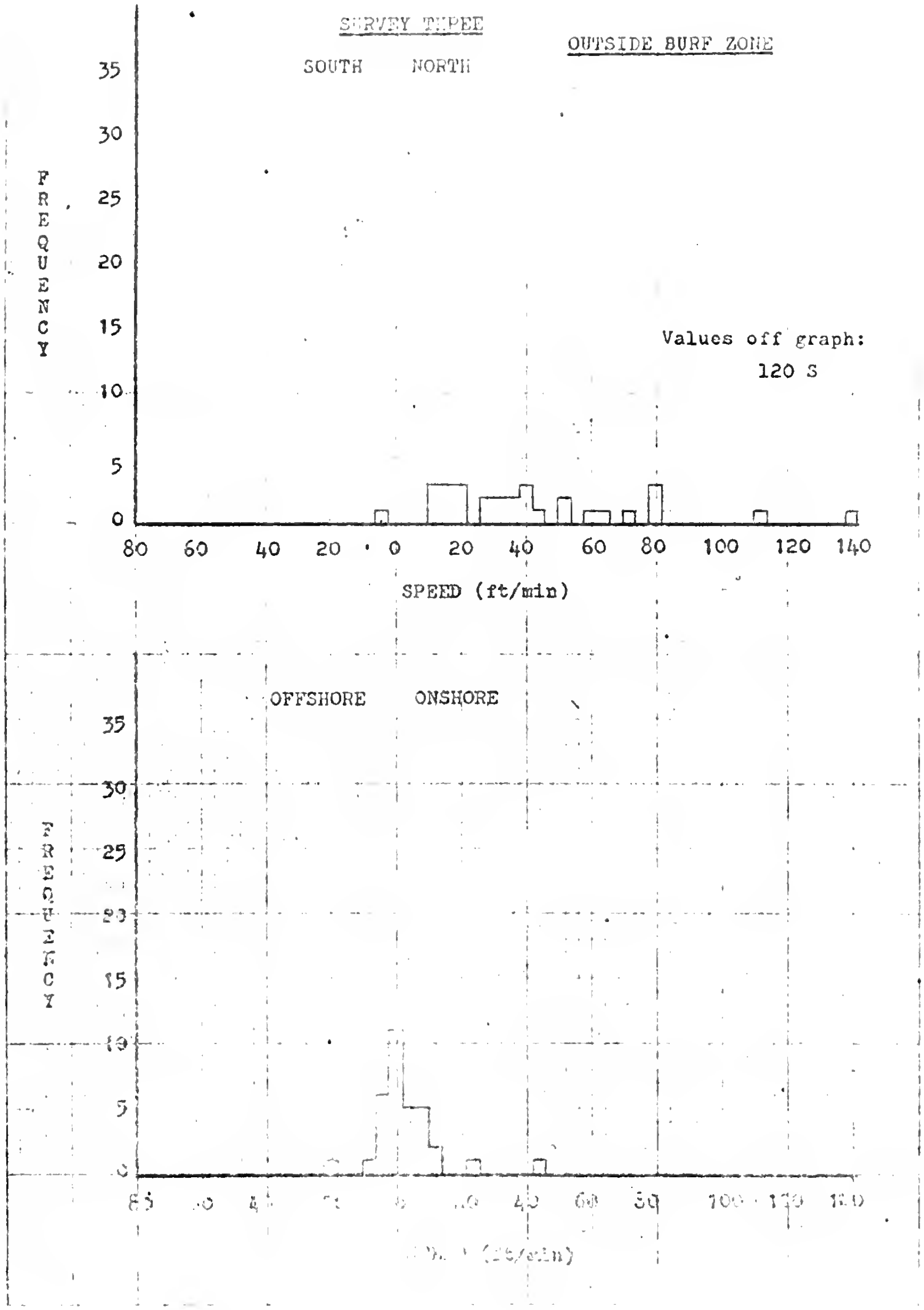


Figure 20. Current Components Outside Surf Zone, Survey Three.

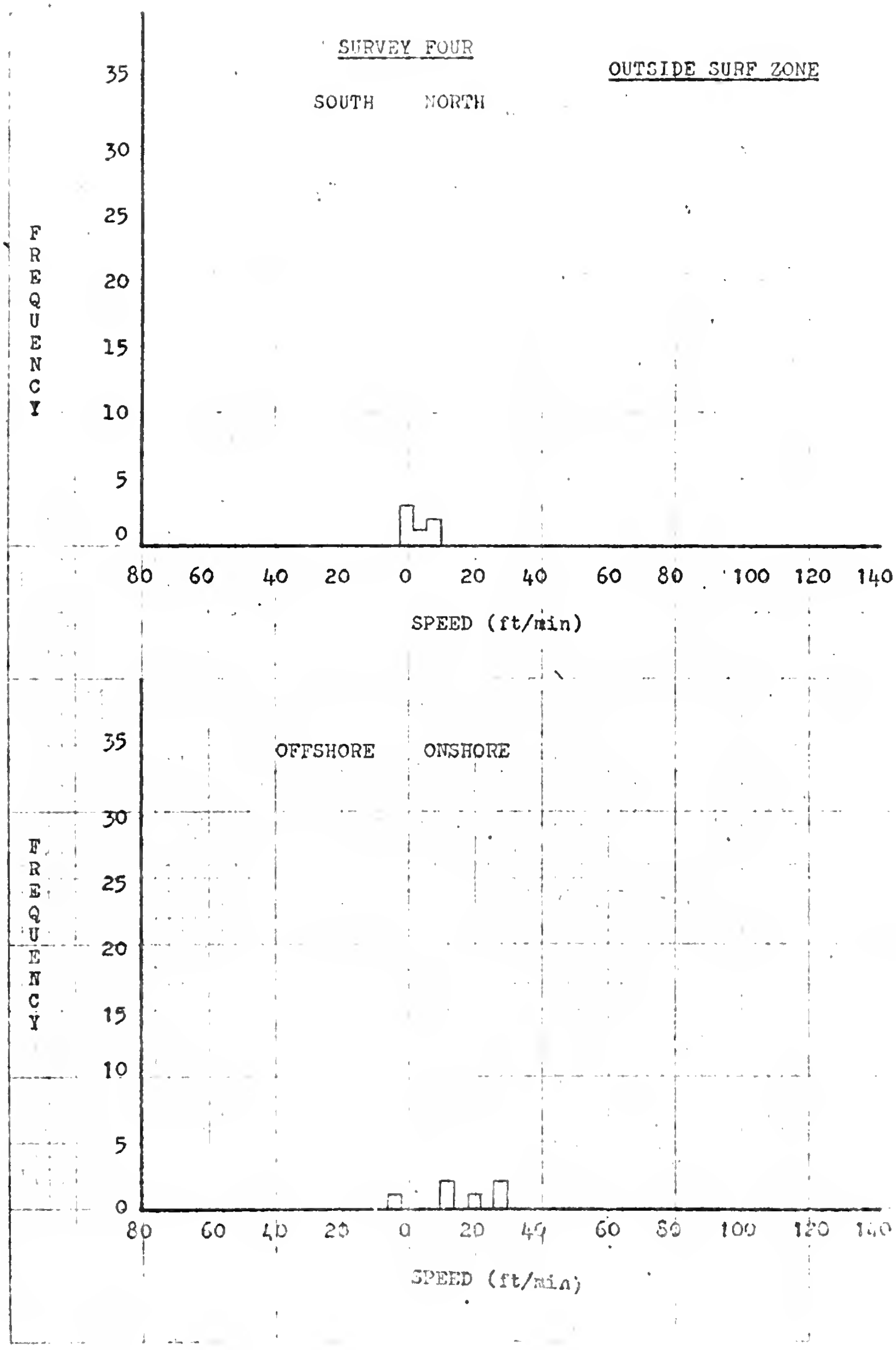


**Figure 21. Current Components Outside Surf Zone, Survey Four.**

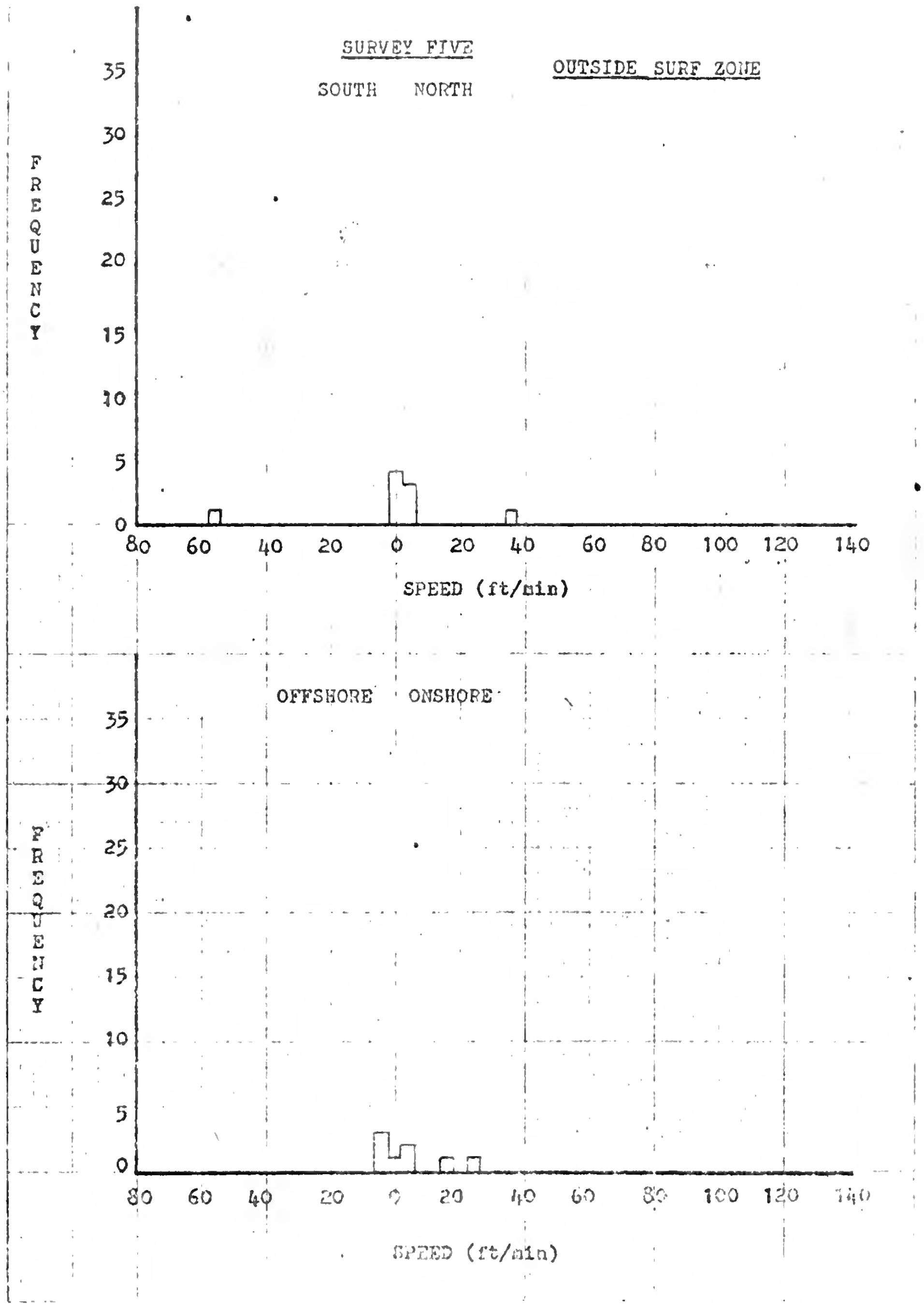


Figure 22. Current Components Outside Surf Zone, Survey Five.

7. Conclusions.

Wind and wave conditions were nearly the same during the five surveys, so that the observed nearshore circulations can be considered to be comparable to each other. The wind was directly onshore, except in Survey Three when the wind had a component along the beach toward the north. In all surveys, the flow was dominantly to the north along the beach, with some cellular circulation always present.

The onshore current approached normal to the beach and its shoreward drift velocity was greater than the speed of the opposing rip currents both outside and inside the surf zone. Survey Three was an exception, because, although onshore flow dominated, the wave current and the rip currents were nearly equal in strength. The onshore drift speed was the same (about 15.0 ft/min) outside and inside the surf zone, but was a little greater (23.7 ft/min) in the transition zone from sea to surf.

The longshore current inside the surf zone was northerly in every survey, but seaward of the surf zone there was no definite longshore flow except in Survey Three when it was to the north. Southerly feeder currents were present with many of the rips, and in many cases caused a convergence of floats on the beach at the base of the rip.

Rip currents occurred all along the beach. Their positions usually varied from one survey to the next, but one rip (near station 13) was observed to occupy the same location during all of the surveys. Rip-current speeds were moderate (10.2 ft/min) within the surf zone, greatest (21.3 ft/min) where the rips passed through the breaker line, and weak (4.8 ft/min) seaward of the surf zone where they became diffuse.

Because the wind and wave conditions were nearly the same for all surveys, no conclusions can be drawn from the data about the nearshore circulation under other weather and sea conditions. Different conditions of wind, waves, and tides would also have been desirable to obtain a broader picture of the circulation patterns present on the selected beach, but the complexity of coordinating the surveys required that the survey dates be fixed well in advance, thus preventing the gathering of data when the environmental conditions were most favorable. The similarity of conditions during the surveys was entirely coincidental and not pre-planned.

Numerous equations for the prediction of longshore currents on a sand beach have been presented in the literature [3]. Examination of the survey results contained herein indicates that caution should be used in developing or applying such equations to describe the velocity of longshore currents because they probably are neither uniform nor simple on any sand beach along the coasts of the oceans.

## REFERENCES


1. Beach Erosion Board, Corps of Engineers. Longshore current observations in Southern California, Technical Memorandum No. 13. 1950.

2. Coast and Geodetic Survey, Smooth Sheet No. H-296. 1851.

3. King, C. A. M. Beaches and Coasts. Edward Arnold, Ltd. 1959.

4. Shepard, F. P., K. O. Emery, and E. C. LaFond. Rip currents: a process of geological importance. The Journal of Geology, v. 49, no. 4, 1941: 337-369.

5. Shepard, F. P., and D. L. Inman. Nearshore water circulation related to bottom topography and wave refraction. Transactions, American Geophysical Union, v. 31, no. 2, 1950: 196-212.

# APPENDIX

## EXPERIMENTATION WITH VARIOUS TYPES OF FLOATS

Before the circulation studies began, the writers experimented extensively with a variety of types of floats in order to find a design that would best satisfy the requirements of the aerial survey procedure that was selected. Some of the basic requirements were that the floats had to reflect the surface water motion as closely as possible, be visible from an aircraft, and show up well in the color photographs against both a dark-blue background outside the surf zone and a white background in the surf zone. As a result, the floats had to be large and brightly colored. The various kinds of floats that were tested, along with their advantages and disadvantages, are outlined below:

I. Wooden boards:

A. Sheets of wood: Sheets of wood veneer (one-eighth inch) were cut into two-foot squares and painted red, orange, and silver.

1. Advantages: Worked well outside the surf zone and were easily visible from an aircraft at 1000 feet elevation.

2. Disadvantages: Upon entering the surf zone the boards either planed or turned end-over-end; they did not withstand the beating of a strong surf as they were broken apart.

B. Redwood planks: Inch-thick redwood planks were cut into pieces one foot by three feet and painted red.

1. Advantages: Worked well outside the surf zone, did not break up in the surf, and were recoverable.

2. Disadvantages: Planed over the surf or turned end-over-end, were hard to see from the air, and were not easy to detect in the photographs.

II. Cardboard sheets: Sheets of heavy cardboard were cut into two-foot squares and painted red, orange, and silver. It was hoped that the paint would not only improve their visibility, but also improve their water resistance.

A. Advantages: Worked well outside the surf zone and were easily visible from the air at 1000 feet.

B. Disadvantages: Rolled up or were torn apart in the surf zone; paint did not improve their durability as much as was desired.

III. Weather balloons: A weather balloon filled with water was found effectively to form a unit of water which responds exactly to surface water motions while offering no sail area to the wind. Fluorescent dye was placed inside each balloon prior to filling to indicate leaks or position if the balloon was destroyed. The balloons proved very difficult to handle when full. The best system devised for filling and launching the balloons was to fill each in a 35-gallon trash can lined with kraft paper to avoid puncturing on the rough surfaces of the can, and to throw the can and balloon over the side (Fig. 23). The bottom of the can took the brunt of the impact and was retrieved by an attached line after the balloon floated free. When brightly painted the balloons were readily visible from the air. Prior to filling with water they were inflated with air and spray-painted various colors, although the results were inconclusive as to which color was best. The colors used were red, orange, yellow, metallic copper, metallic brass, metallic silver, metallic gold, and fluorescent red. Standard 300-gram weather balloons were used in these experiments and were filled with both fresh water and salt water.

Figure 23. Launching of a Weather Balloon Float.

A. Fresh-water filled: Balloons were filled completely with fresh water.

1. Filled until distended:

   a. Advantages: Accurately represented the surface current and offered no wind resistance.

   b. Disadvantages: Due to the fact that the balloon was filled until distended, it assumed a spherical shape so that only a small area, about one foot in diameter, was visible from the air. The balloon broke easily upon contact with a rough object and so required very careful handling. It also broke easily in the breakers.

2. Filled but not distended:

   a. Advantages: Buoyancy of the fresh water flattened the balloon out so that an area about two or three feet in diameter was exposed at the water surface, making the float clearly visible from the air at 1000 feet (Fig. 24). The balloon floated awash, unaffected by the wind, and did not break on contact with a rough surface.

   b. Disadvantages: The balloons ruptured in a ten-foot surf although they worked well in a three-foot surf.

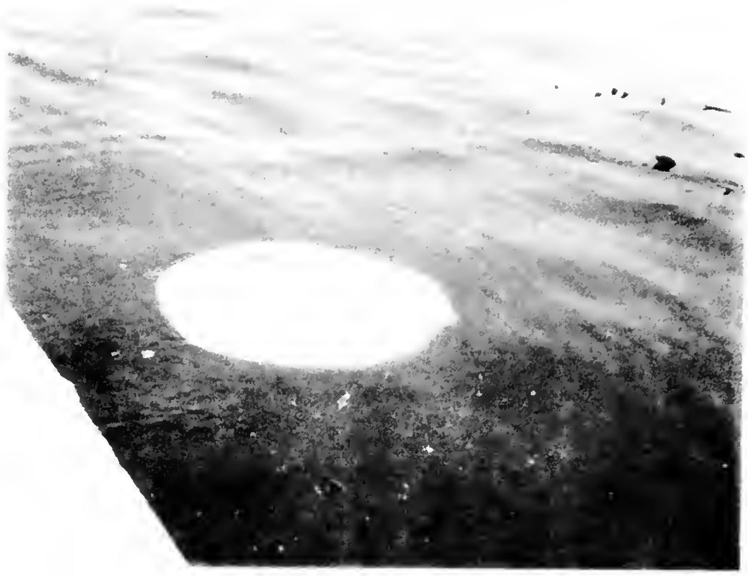

Figure 24. Fresh-water-filled Weather Balloon Afloat.

B. Salt-water filled: A small air space was left in these balloons to provide buoyancy.

1. Advantages: Since they were not filled to the stretching point these balloons did not puncture easily when they came in contact with rough objects.

2. Disadvantages: Since there was no density difference inside or outside the balloon it assumed different shapes depending upon the direction of forces acting on it. The only visible area exposed, about one foot square, was the air pocket which acted as a low sail and was thus subjected to slight wind stress.

IV. Innertubes: Water-filled automobile innertubes were tried. The tubes were painted international yellow, international red, and silver, all of which were satisfactory.

A. Single tubes: Innertubes were painted and filled with fresh water.

1. Advantages: The rubber was strong enough to permit rough handling of the floats in launching and recovery, and withstood rough treatment in the surf zone. The tubes floated flush with the water surface so that there was no wind effect, and apparently conformed well with the currents. They did not plane in the surf.

2. Disadvantages: The single tube was difficult to see in aerial photographs due to its floating flush with the water surface.

B. Double tubes: Two innertubes were lashed together, one on top of the other, with the top tube filled with air and painted for visibility and the bottom one filled with fresh water (Fig. 4). Dye-marker packets were attached to each double innertube float. The floats were observed to leave a well-defined trail of dye which not only gave an excellent means of locating the float in an aerial photograph, but also gave an indication of the track of the float with respect to the surface water motion.

1. Advantages: Although heavy and bulky, these floats could be handled without special launching schemes and were recoverable. They were always visible due to the air-filled tube on top. They were durable and withstood surf action very well with no planing effect.

2. Disadvantages: Exposure of the upper float to the air introduced some wind effect, but presumably inertia of the float largely negated this.

V. Dye packets: Single dye packets tied to small pieces of wood for buoyancy were also tested as individual floats.

A. Advantages: Dye was easy to see in the aerial photographs seaward of the surf zone and the packets were easy to handle.

B. Disadvantages: Dye was difficult to locate in the aerial photographs once the markers reached the surf zone due to the intense turbulent mixing.

Double innertube floats were selected for use in this study because of their durability and their visibility from the air, both in the surf zone and to seaward of it. Although balloons were not used, they are believed to have good potential as a float for tracing surface currents in open water seaward of the surf zone and further experimentation is recommended.

[redacted]